NASA/TM—2012-217747

CoNNeCT Antenna Positioning System Dynamic Simulator Modal Model Correlation

Trevor M. Jones, Mark E. McNelis, Lucas D. Staab, James C. Akers,
and Vicente J. Suarez
Glenn Research Center, Cleveland, Ohio

October 2012

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Prepared for the
Spacecraft and Launch Vehicle Dynamic Environments Workshop
sponsored by the Aerospace Corporation
El Segundo, California, June 19–21, 2012

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

October 2012

Level of Review: This material has been technically reviewed by technical management.

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1.0 Introduction

1.1 Background

The National Aeronautics and Space Administration (NASA) developed an on-orbit, adaptable, Software Defined Radios (SDR)/Space Telecommunications Radio System (STRS)-based testbed facility to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities on the International Space Station (ISS). The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) Project will provide NASA, industry, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in both the laboratory and space environment based on reconfigurable, software-defined radio platforms and the STRS Architecture. The CoNNeCT Payload Operations Nomenclature is "SCAN Testbed," and this nomenclature will be used in all ISS integration, safety, verification, and operations documentation. The SCAN Testbed (payload) is a Flight Releasable Attachment Mechanism (FRAM) based payload that will launch aboard the Japanese H-II Transfer Vehicle (HTV) Multipurpose Exposed Pallet (EP-MP) to the International Space Station (ISS), and will be transferred to the Express Logistics Carrier 3 (ELC3) via Extravehicular Robotics (EVR). The SCAN Testbed will operate on-orbit for a minimum of two years.

One major subsystem of the CoNNeCT system is the Antenna Pointing System (APS). The APS is attached to the top of the CoNNeCT payload (Fig. 1). System-level protoflight random vibration testing of CoNNeCT was required. Due to the APS flight system's lengthy development schedule, the flight APS hardware was not available at the time of the CoNNeCT system-level protoflight random vibration test. Previous random vibration analysis has shown that the dynamics of the APS has a large effect on the loading seen by other subsystems during random vibration input. Because of this, a dynamic APS mass simulator was designed, fabricated, and used during the CoNNeCT system level protoflight random vibration test.

1.2 Purpose of Model Correlation

The APS simulator modal survey was conducted to validate the APS dynamic simulator finite element model (FEM). A modal survey was performed experimentally using a modal hammer to identify the frequencies, damping values, and mode shapes for the primary resonant modes of the assembly. The APS simulator FEM was correlated by updating the model to represent the test mode shapes.

The test-correlated APS dynamic simulator FEM was analytically integrated with the CoNNeCT system protoflight FEM in the test configuration. A random vibration analysis of the CoNNeCT system protoflight FEM was conducted later and verified the APS dynamic simulator behaves similarly to the FEM of the APS actual flight hardware. Once verified, the APS dynamic simulator hardware was accepted for use during the CoNNeCT system test.

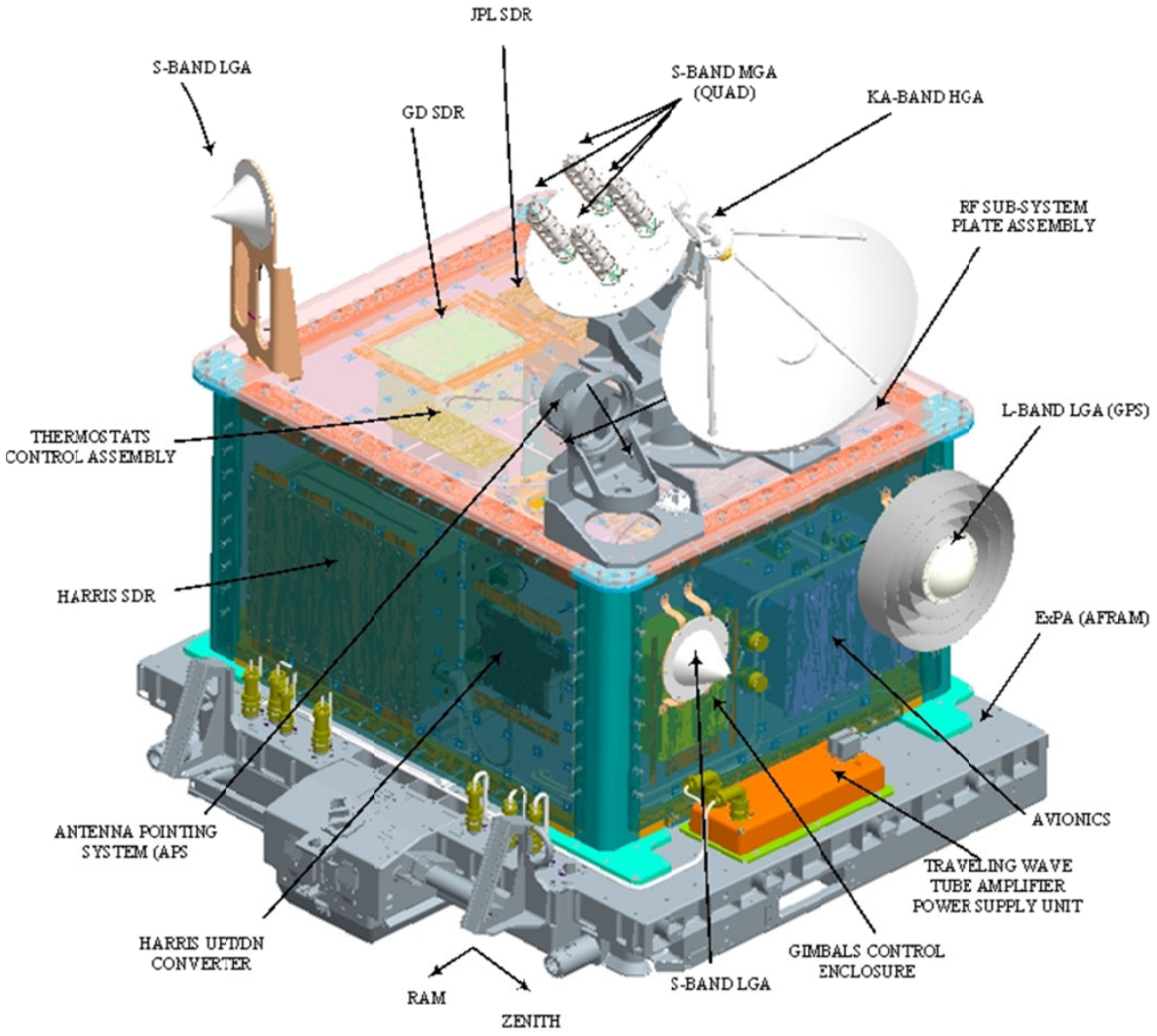


Figure 1.—CoNNeCT system hardware in flight configuration.

1.3 Applicable Documents

1. "CoNNeCT Project System Vibration Test Plan," GRC-CONN-PLAN-0250 Base.
2. "Verification & Validation Procedure, CoNNeCT," GRC-CONN-PROCEDURE-0012.
3. "APS Dynamic Simulator Impact Test Procedure," GRC-CONN-PRO-0582.
4. "Flight System Requirements, CoNNeCT," GRC-CONN-SRD-0035 Rev A.
5. "Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures," SSP 52005, Revision C, Section 7.1 Verification Requirements for Dynamic Structural Models, December 18, 2002.
6. "Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) Antenna Positioning System (APS) Dynamic Simulator Modal Survey Test Report," SDL-TR 11-05.

2.0 Model Correlation Goals

Per SSP 52005, Section 7.1, the model correlation goal for the target mode, in each axis, for modal frequency was ±5 percent of the difference between test data and the correlated model. The correlation goal for higher order modes was a frequency difference of ±10 percent.

Cross-orthogonality between analytical and test mode shapes is evaluated based on the following equation:

$$[\emptyset]_A^T [M]_A [\emptyset]_T = [C_{ij}]$$

where

$[\emptyset]_A^T$ is the transpose of the analytical mode shape matrix

$[M]_A$ is the analytical consistent mass matrix (as defined in NASTRAN manuals)

$[\emptyset]_T$ is the test mode shape matrix

$[C_{ij}]$ is the correlation matrix

The correlation goal was for the magnitude of the diagonal terms of the correlation matrix, $[C_{ij}]$, to be greater than 0.9 for target modes. The correlation goal for the off-diagonal terms was a magnitude less than 0.1 for the target modes. This diagonal and off-diagonal criteria assumes no modal pairs, triples, etc.

3.0 Test Hardware

The APS simulator hardware is a high-fidelity dynamic simulator intended for use during the CoNNeCT flight system vibration test. The simulator consists of a "flight-like" simulator base, two actuator mass simulators, an L-bracket, an arm frame assembly, and two antenna simulators; a High Gain Antenna (HGA) and Medium Gain Antenna (MGA) (Fig. 2). The arm frame is connected to the simulator

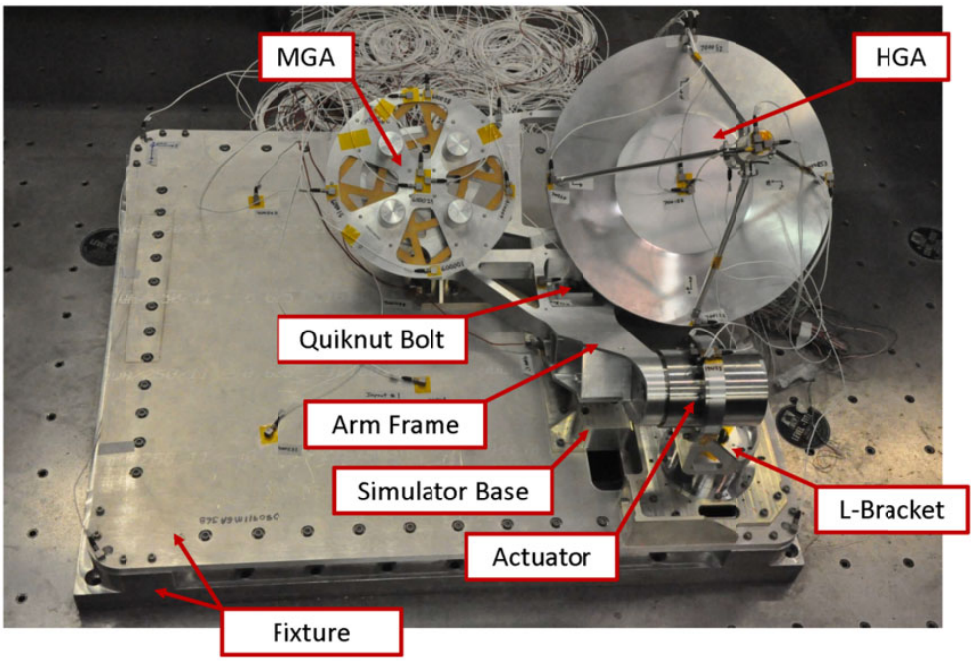


Figure 2.—APS dynamic simulator test article and fixture components.

base through the L-bracket/actuator assembly and the Quiknut bolt. Table 2 summarizes the test article component weights. The total weight of the simulator base was 38 lb and the total weight of the APS arm assembly (L-bracket, arm frame, two actuators and two antennas) was 27.5 lb.

The APS dynamic simulator hardware was mounted to a modal fixture for the modal test (Fig. 2). The fixture was mounted to a fixed-base modal floor. The modal fixture was designed to mimic the top panel of the full CoNNeCT flight hardware. The modal fixture consists of a stiff rectangular frame whose dimensions match that of the full CoNNeCT flight hardware and a mounting plate of similar material and the same thickness as the top panel of the full CoNNeCT flight hardware.

4.0 FEM Model Description

The APS dynamic simulator modal test configuration FEM is shown in Figure 3. The FEM was created using NX-Ideas 6 software using the flight APS FEM as a starting point. The FEM was analyzed using MSC Nastran 2008. The model consists mainly of shell elements. A summary of the FEM from Nastran is shown in Table 1. Figure 3 illustrates the APS dynamic simulator coordinate system which is consistent with the coordinate system of the system level CoNNeCT FEM. A summary of the FEM weights and a comparison against the actual test article weights can be found in Table 2.

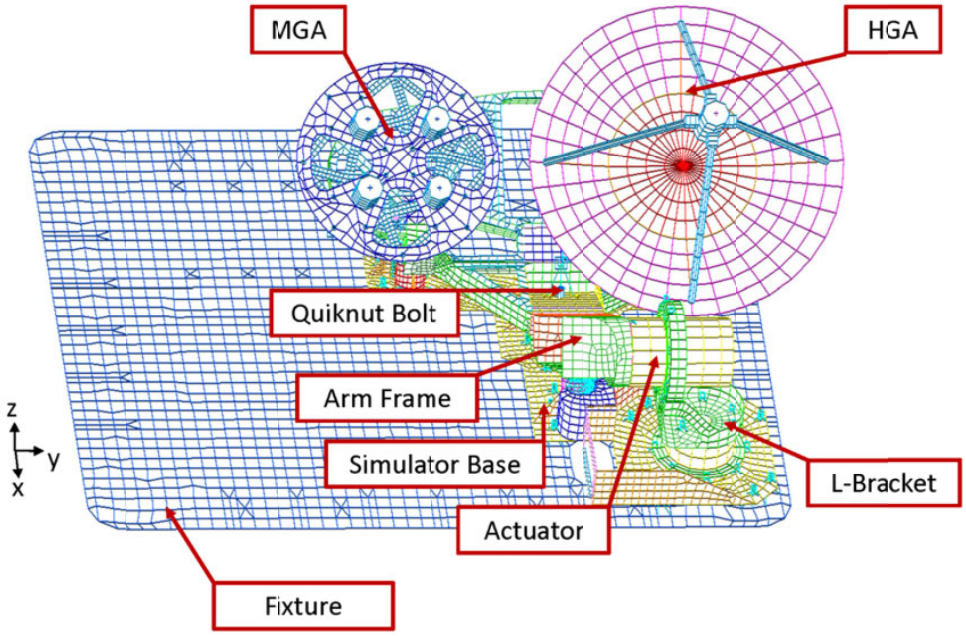


Figure 3.—APS Dynamic simulator Finite Element Model.

TABLE 1.—APS DYNAMIC SIMULATOR MODEL
SUMMARY FROM MSC NASTRAN 2008

NUMBER OF GRID	POINTS	=	13826
NUMBER OF CBAR	ELEMENTS	=	60
NUMBER OF CBEAM	ELEMENTS	=	35
NUMBER OF CHEXA	ELEMENTS	=	380
NUMBER OF CONM2	ELEMENTS	=	2
NUMBER OF CPENTA	ELEMENTS	=	42
NUMBER OF CQUAD4	ELEMENTS	=	11319
NUMBER OF CTETRA	ELEMENTS	=	2185
NUMBER OF CTRIA3	ELEMENTS	=	794
NUMBER OF RBE2	ELEMENTS	=	368

TABLE 2.—COMPONENT WEIGHTS TEST ARTICLE VERSUS
BASELINE SIMULATOR FEM

Component	Test Article (lbs)	Baseline FEM (lbs)	%diff vs. test
Fixture Base Plate	82.5	82.7	0.2
APS Base	38	36.2	4.7
APS Arm Frame Assembly	27.5	34.2	24.4
APS Total	65.5	70.4	7.5
Test Configuration Total	148	153.1	3.4

5.0 Pre-Test Analysis

A pre-test modal analysis was performed to identify the target modes of the APS dynamic simulator hardware and test fixture. The criteria used to select target modes was based on the model effective mass of each mode. Modes with an effective mass fraction greater than 10 percent would be primary target modes. Table 3 is the modal effective mass table for the baseline APS dynamic simulator and test fixture FEM produced using MSC Nastran 2008. Only the 116.7 Hz translational mode had an effective mass fraction greater than 10 percent, and thus was selected as the only target mode. This mode shape is dominated by the global “oil canning” of the fixture plate in the Z-direction.

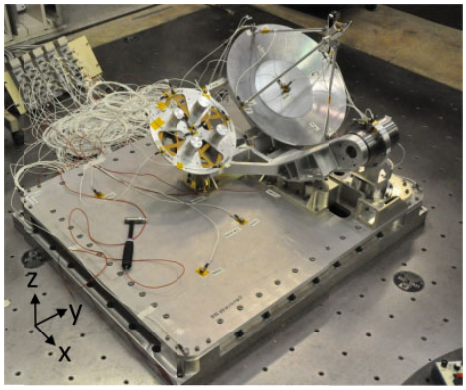
The pretest analysis was also used to help determine acceptable instrumentation locations for the modal survey test. Accelerometer locations were determined using a combination of FEM kinetic energy and engineering judgment. The final instrumentation set included thirty eight (38) degrees of freedom. A Test Display Model (TDM), which is part of the Test Analysis Model (TAM), was developed to assist with mode extraction and mode shape visualization during testing. The TDM is a geometric model that only contains nodes at the instrumentation locations and is shown at the bottom of Figure 4.

TABLE 3.—EFFECTIVE MASS (%) TABLE FOR BASELINE FEM

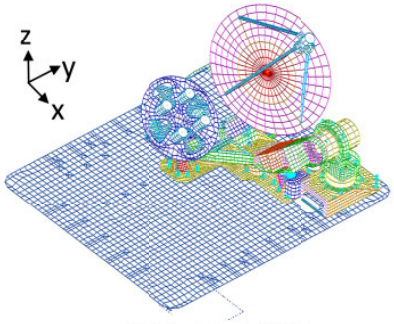
	Hz	x	y	z	rx	ry	rz
1	95.59	1	3	5	6	2	0
2	105.78	1	0	4	0	2	1
3	116.70	2	1	24	1	3	0
4	131.62	7	2	0	2	11	0
5	166.57	4	3	0	4	8	13
6	172.52	0	1	6	0	0	0
7	189.77	0	0	2	0	0	0
8	193.54	0	0	3	1	1	1
9	204.96	1	3	1	5	2	0
10	224.74	1	3	0	4	1	0

Target Mode

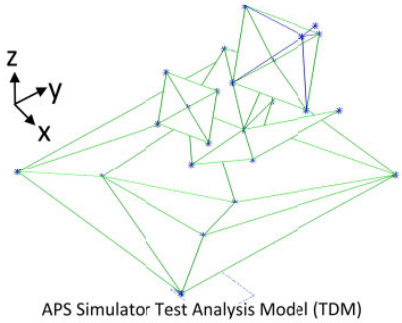
Key:
- MEF Between 5% and 20%
- MEF Greater than 20%



APS Simulator Test Setup



APS Simulator Full FEM



APS Simulator Test Analysis Model (TDM)

Figure 4.—Full APS Dynamic simulator Hardware (top), FEM (middle), and TDM (bottom).

6.0 Test Results

A modal survey using a modal hammer was conducted on the CoNNeCT APS dynamic simulator from November 22 to 24, 2010, at the NASA Glenn Research Center Structural Dynamics Laboratory (SDL). The CoNNeCT APS Dynamic Simulator and its fixture were installed on the SDL fixed base modal floor.

The pretest analysis predicted the frequency of the target mode to be 116.7 Hz (dominated by global Z-direction oil canning of the fixture plate). The initial modal survey test found the frequency of the target mode to be 161.5 Hz, which is a 44.8 Hz difference and 27.7 percent higher than the FEM prediction. Also, not surprisingly, the FEM and test mode shapes had significant differences. Hence a model correlation starting at this assembly model level was judged not to be feasible. Therefore, the modal survey and model correlation scope was expanded to include a component (i.e., modal fixture only) and a subassembly (i.e., modal fixture and APS dynamic simulator with both antennas removed). In order to expedite the modal testing, the order the modal tests were performed coincided with the assigned configuration numbering.

Configuration 1: Modal fixture and fully assembled APS dynamic simulator
Configuration 2: Modal fixture and APS dynamic simulator with both antennas removed
Configuration 3: Modal fixture only

The model correlation effort was performed in the reverse order to allow a building block approach, which made this task manageable.

Time history data was processed into frequency response functions (FRF's), coherence, and auto spectra. Data quality checks were performed to ensure good quality test data. The initial data quality check was the visual inspection of the time histories. The next data quality check was the inspection of FRF's, which showed there was minimal measurement noise in the frequency range of interest (100 to 300 Hz) and well defined resonance peaks. Move response mode shapes, extracted well below the first FRF resonance peaks, provided a final data quality check of the instrumentation and the data acquisition system. Figures 5 to 7 show FRF plots for the three configurations tested. The plots include the responses of all the in-line accelerometers. Time-domain polyreference was the method used for mode extraction. The residual fits looked very good. A multivariate mode indicator function (MMIF) was used to aid in the modal extraction. The MMIF lined up well with the FRF resonance peaks of the modes of interest. Figure 8 is a stability plot showing the pole estimates with the MMIF overlaid for Configuration 1. Modal extraction was relatively straight forward for this test and did not require any manual "tweaking" of the extracted modal parameters. Table 4 lists the extracted modes and mode shape descriptions for each of the three configurations.

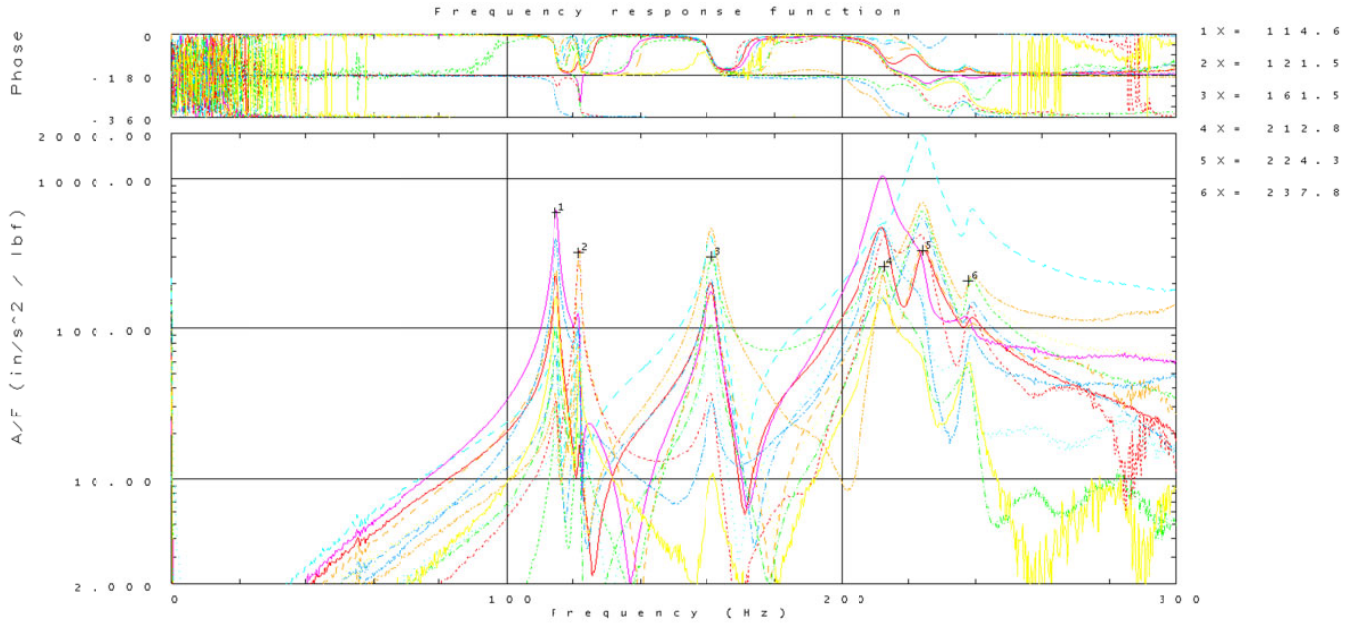


Figure 5.—Configuration 1 in-line accelerometers FRF plot.

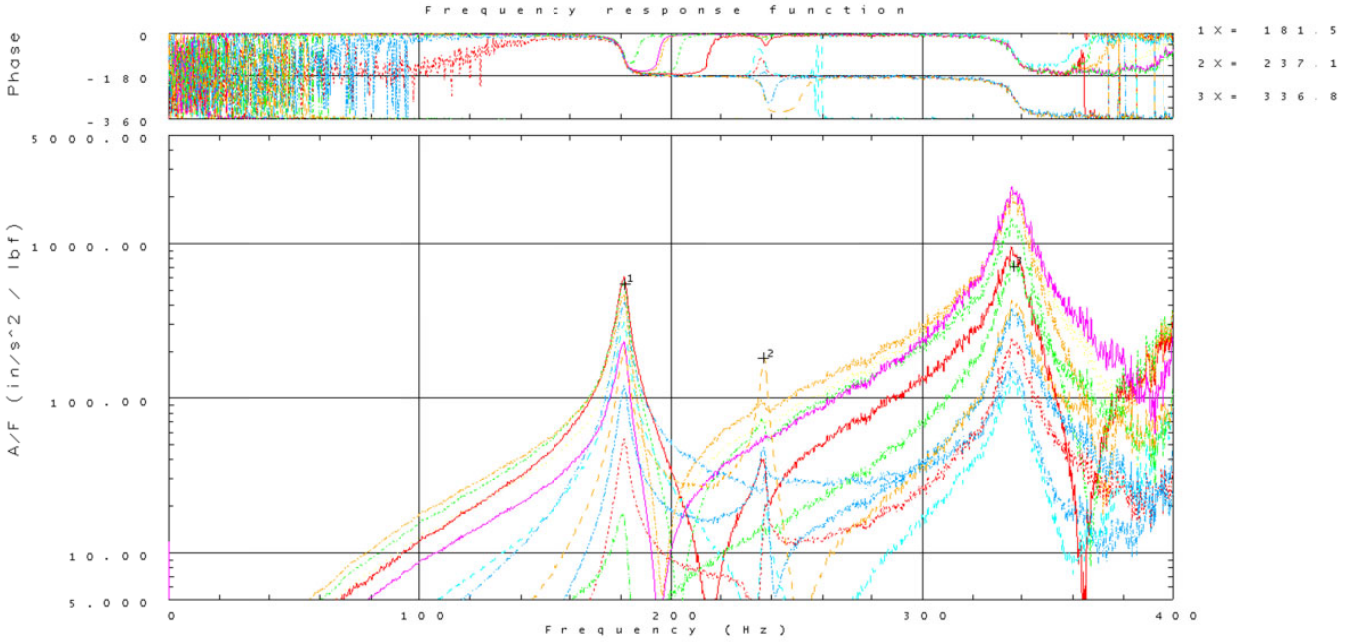


Figure 6.—Configuration 2 in-line accelerometers FRF plot.

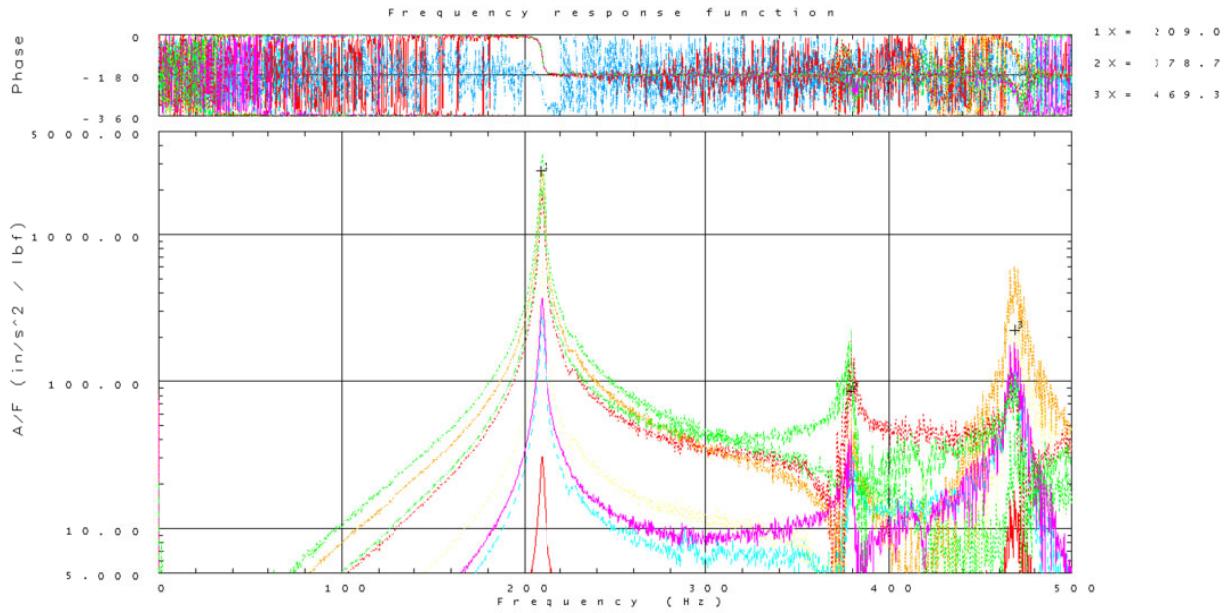


Figure 7.—Configuration 3 in-line accelerometers FRF plot.

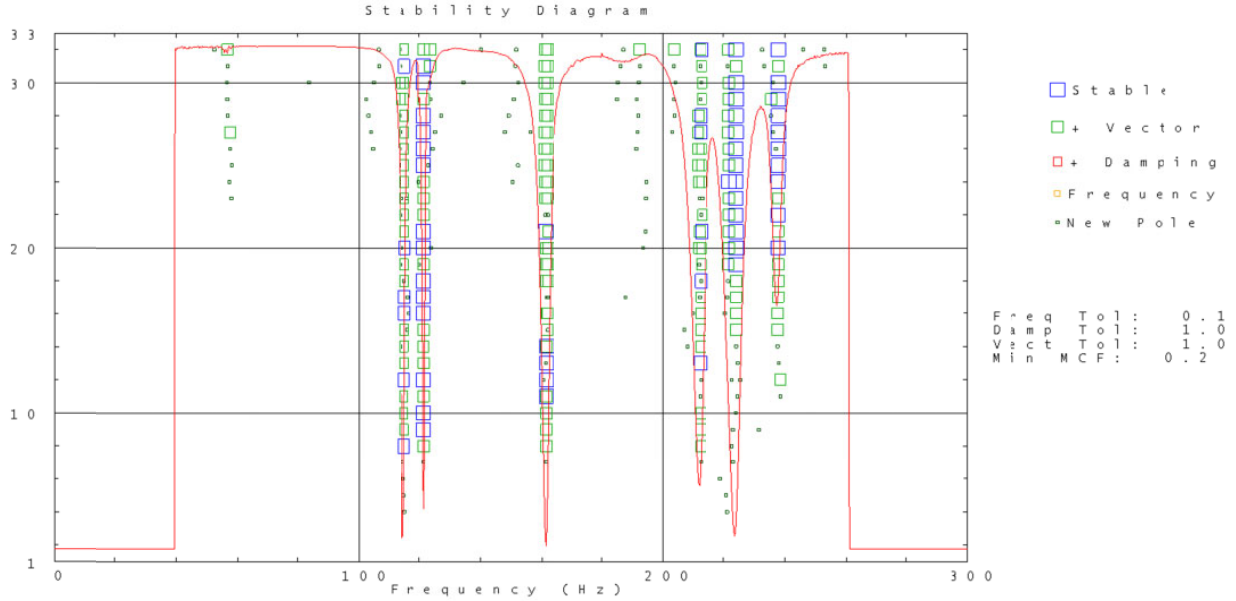


Figure 8.—Stability diagram with MMIF overlaid for configuration 1.

TABLE 4.—TEST MODES AND MODE SHAPE DESCRIPTIONS

Configuration 1: Fully Assembled APS Dynamic simulator

Mode #	Freq (Hz)	Mode Shape Description
1	114.8	HGA Bending X Direction
2	121.6	HGA Bending Y Direction
3	161.5	Global Z Direction Bending HGA Out of Phase
4	212.7	APS Arm Bending About Y
5	224.3	MGA X Direction Mode
6	237.9	Actuator Moving in X/Y Direction

Configuration 2: APS Dynamic simulator With HGA and MGA Removed

Mode #	Freq (Hz)	Mode Shape Description
1	181.4	Panel Mode Z APS in Phase
2	237.1	Actuator Moving in X/Y Direction
3	336.8	APS Arm Bending About Y

Configuration 3: APS Dynamic simulator Removed - Fixture Only

Mode #	Freq (Hz)	Mode Shape Description
1	209.2	Panel Mode Z (One Node)
2	379.0	Panel Mode Z (Two Nodes in Y)
3	469.5	Panel Mode Z (Two Nodes in X)

7.0 Model Correlation

7.1 Correlation Methodology

The APS Dynamic Simulator correlation methodology was based on a building block approach using three configurations (correlation steps). The three correlation steps correspond with the three test configurations. The correlation was conducted in reverse order with respect to the order the modal tests were performed. The three correlation steps were as follows:

Step 1 was the correlation of the FEM of the fixture base plate by itself, without the APS dynamic simulator, to test configuration 3 test data. The goal here was to get the dynamics of the fixture base plate by itself correct.

Step 2 involved adding the APS dynamic simulator, but without the antennas, to the correlated fixture base plate FEM from Step 1 and correlating this model to test configuration 2 test data.

Step 3 involved correlating the full FEM, which incorporated the correlated components from Step 2, to test configuration 1 test data. Figure 9 shows the FEM for each of the three model correlation steps.

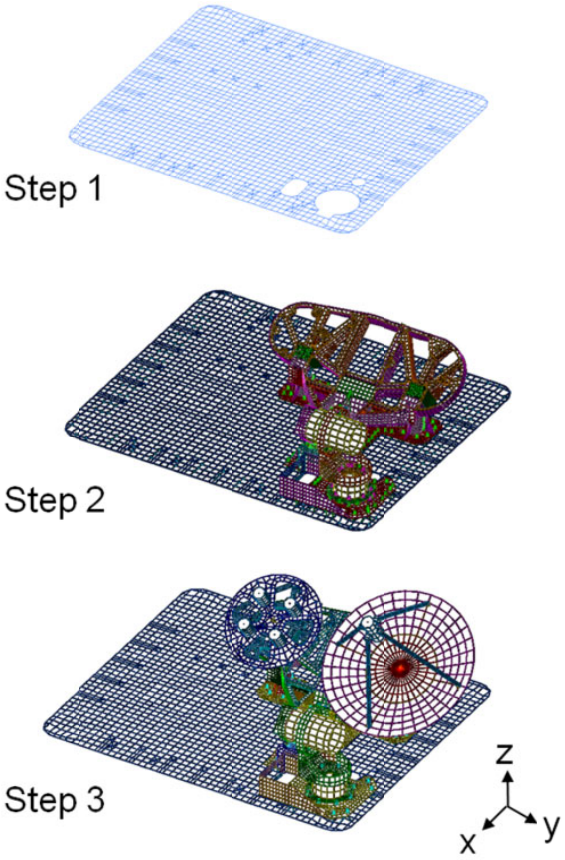


Figure 9.—Model correlation stepwise approach.

7.2 Step 1: Fixture Base Plate Correlation

The first step was correlation of the base plate alone. Figure 10 shows the test setup for this configuration. A modal survey test was conducted on this configuration, and three test modes were extracted, which were used as target modes for this configuration. The frequencies of these modes are given in Table 5. The shapes for the three modes are shown in Figure 11. The baseline FEM was run using MSC Nastran 2008 solution 103 normal modes; Table 5 summarizes the corresponding predictions for the three modes from the baseline FEM. The FEM predictions are lower in frequency by 10 percent or more as compared to the test results. The FEM needs to be stiffened to achieve correlation.

In order to stiffen the model, three modifications were considered: the thickness of the fixture base plate, its material properties, and the boundary condition. The fixture base plate thicknesses of the FEM and hardware were dimensionally verified with a micrometer. The fixture base plate is machined out of aluminum. The FEM material properties were also verified. Examining the fixture base plate hardware revealed that the boundary condition was likely not accurately represented in the baseline FEM. The baseline FEM boundary condition fixed the fixture base plate at the bolt locations in the three orthogonal directions (i.e., fixed in translation but free to rotate). The fixture base plate hardware sits on a 2-in.-wide flange and is probably more accurately modeled as being fixed in translation as well as in rotation (except about the axis of the fastener). This rotational constraint was added to the FEM, and the resulting frequencies are given in Table 5. The frequency differences dropped to under 2 percent. A visual comparison of the FEM and test mode shapes using the TDM showed good agreement for all three modes. Hence, the fixture base plate is considered to be correlated.

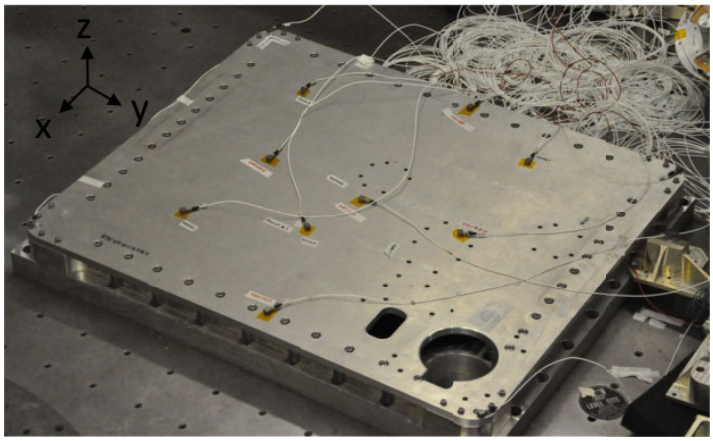
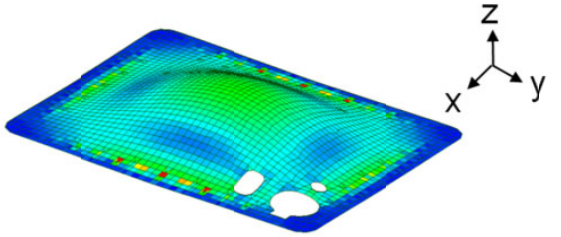


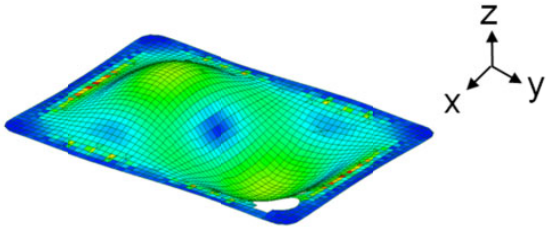
Figure 10.—Fixture base plate test setup.

TABLE 5.—FIXTURE BASE PLATE CORRELATION

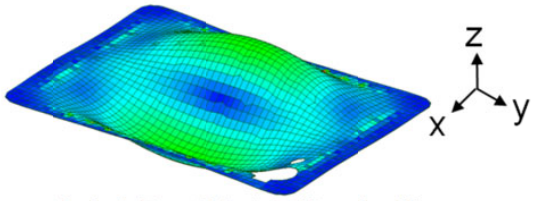
		Test	FEM		FEM new BC	
Mode#	Description	Hz	Hz	%diff	Hz	%diff
1	Panel Mode Z	209.3	183.5	12.3	211.8	1.2
2	Panel Mode Z (2 nodes in Y)	379.0	341.4	9.9	384.2	1.4
3	Panel Mode Z (2 nodes in X)	469.5	408.3	13.0	473.2	0.8



Mode 1: Panel Mode Z
(209.3 Hz Test Frequency)



Mode 2: Panel Mode Z (2 nodes Y)
(379.0 Hz Test Frequency)



Mode 3: Panel Mode Z (2 nodes X)
(469.5 Hz Test Frequency)

Figure 11.—Fixture base plate FEM mode shapes.

7.3 Step 2: APS With HGA and MGA Removed Correlation

With the fixture base plate FEM well correlated, the second step was to begin correlation of the APS dynamic simulator hardware. The FEM to be correlated in Step 2 added the APS dynamic simulator hardware with the two antennas removed (HGA and MGA) to the correlated base plate FEM from Step 1. A modal test was conducted on the APS Dynamic simulator assembly in this configuration, and three test modes were extracted. The comparison of the analytical and test modal frequencies is given in Table 6. The modal effective mass (MEF) table for the Step 2 baseline and correlated FEM is also given in Table 6. A visual inspection of the FEM versus test mode shapes (using the TDM) was performed for each of the three modes. Based on visual inspection, the three test modes appear to match with the first three modes of the FEM. FEM Mode 1 has the highest effective mass at 33 percent in the Z-direction. The shape of Mode 1 also seems to compare well with the target mode identified in the pretest analysis and can be described as the global panel mode in the Z-direction. Because this is the mode of interest, the correlation effort for Step 2 was focused on closely matching the frequency of Mode 1 to the test results. For mode 1 the FEM prediction was 156.77 Hz and the modal survey test showed the same mode to be 181.36 Hz, which is 13.56 percent higher, necessitating modification of the FEM.

In order to increase the FEM mode 1 modal frequency, several correlation parameters were considered to stiffen the model: the thickness of the parts, the material properties used, the mass, and the boundary condition connecting various components. As with the base plate, a micrometer was used to measure thicknesses of the APS dynamic simulator hardware and they agree well with the FEM properties. The FEM material properties were also verified to be correct. Table 2 compares the FEM components weights to those of the actual hardware. The weight differences for the APS base and APS arm frame assembly are about 5 and 25 percent, respectively. The FEM contained some non-structural mass which was adjusted to help bring the FEM into closer alignment with the actual weights of the hardware.

With the first three correlation parameters exhausted, the remaining parameter was the boundary condition between the various components. The interface between the fixture base plate and the APS dynamic simulator base was considered first (Fig. 12). Additional RBE2 elements (constrained in all degrees of freedom) were added to the FEM in an attempt to more accurately represent that interface. Approximately thirty RBE2 elements were added. The elements connect nodes on the fixture base plate to nodes on the APS dynamic simulator base. This change did increase the resulting frequency of mode 1. The next boundary condition examined was the kinematic pins connecting the APS arm frame to the APS base (Fig. 12). The pins in the model had rotational degrees of freedom released. It was determined that due to a stiff connection and possible friction at these locations the connection would be better modeled as fixed in translation as well as in rotation. This change was implemented in the FEM. The final boundary condition taken into consideration was the interface between the actuators and the L-bracket. Additional RBE2 elements (constrained in all degrees of freedom) were added here to account for the relatively thick flange at those joints. Eight spider RBE2 elements were added around the circumference of the two joints between the existing RBE2 elements. The existing RBE 2 elements are at the fastener locations. With all these changes implemented collectively, the frequency of Mode 1 increased to 184.81 Hz, which was less than 2 percent from the test modal frequency. Subsequently, the percent error for Mode 2 and 3 were also decreased. Table 6 contains the updated effective mass table for the correlated APS dynamic simulator without antennas model. Visual inspection the FEM mode shapes and test modes, visualized using the TDM, showed good agreement. With the frequencies and mode shapes matching well, the APS dynamic simulator without antennas is considered to be correlated.

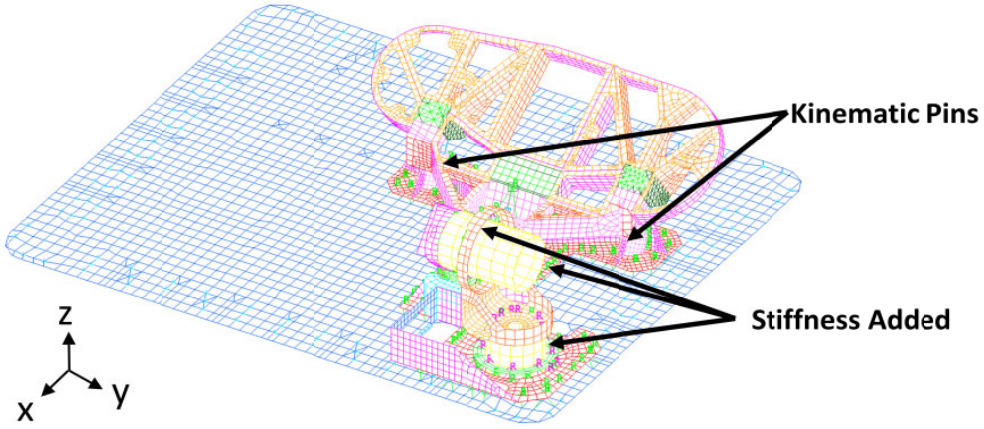


Figure 12.—APS dynamic simulator with HGA and MGA removed; model updates.

TABLE 6.—APS WITH HGA AND MGA REMOVED EFFECTIVE MASS TABLES

Test Results	Baseline FEM: HGA and MGA Removed (Baseplate Correlated)								Correlated FEM: HGA and MGA Removed								
Frequency (Hz)		Hz	%diff vs. test	x	y	z	rx	ry	rz		Hz	%diff vs. test	x	y	z	rx	ry	rz
181.36	1	156.77	13.56	4	1	33	1	5	1	1	184.81	1.90	0	3	39	4	0	0
237.15	2	166.32	29.87	5	6	2	7	9	10	2	225.12	5.07	5	3	0	3	11	10
336.83	3	239.15	29.00	2	2	1	2	5	0	3	294.24	12.64	1	0	1	0	3	1
	4	258.54	N/A	2	0	0	1	2	2	4	380.46	N/A	7	0	0	0	9	0
	5	280.53	N/A	1	4	19	13	5	0	5	385.34	N/A	1	2	0	1	0	1
	6	314.03	N/A	0	0	0	0	0	0	6	467.29	N/A	1	0	0	2	0	0
	7	314.62	N/A	2	1	0	0	1	1	7	506.78	N/A	0	1	11	6	3	0
	8	361.75	N/A	0	1	0	2	0	0	8	523.71	N/A	0	6	2	7	0	0
	9	398.19	N/A	0	3	4	2	0	0	9	559.65	N/A	0	0	2	2	0	0
	10	437.76	N/A	1	2	1	6	1	0	10	610.18	N/A	3	0	0	1	5	0

Key: MEF Between 5% and 20%; MEF Greater than 20%

7.4 Step 3 Full APS Dynamic Simulator Correlation

With the first two correlation steps successfully completed, the final step was to correlate the full APS dynamic simulator FEM. The model used in Step 3 was the correlated model from Step 2 with the uncorrelated antennas (MGA and HGA) added. A modal test was conducted on the APS Dynamic simulator assembly in this fully assembled configuration, and six test modes were extracted. Mode 3 was the global panel mode in the Z-direction and is also the target mode for correlation based on the pretest analysis. Table 7 shows the MEF table for the correlated model from Step 2 with the uncorrelated antennas attached. The FEM target mode modal frequency is 141.29 Hz while the test modal frequency is 161.54 Hz, which is 12.53 percent higher. Hence the FEM was judged to be not correlated and needed to be modified. Modes 1 and 2 were selected as secondary modes for correlation. Similar to Mode 3, the target mode, the test modal frequencies for these secondary modes were higher than the corresponding FEM modal frequencies.

TABLE 7.—FULL APS DYNAMIC SIMULATOR EFFECTIVE MASS TABLES

Test Results		Baseline FEM: Full APS Simulator (Baseplate and Arm Correlated)							Correlated FEM: Full APS Simulator							
	Frequency (Hz)		Hz	%diff vs. test	x	y	z	rx	ry	rz	Hz	%diff vs. test	x	y	z	rx	ry	rz
Secondary Modes	114.83	1	101.10	11.96	0	2	1	4	1	0	116.95	1.85	2	0	0	1	3	1
	121.58	2	110.36	9.23	1	0	0	0	3	2	121.55	0.03	0	2	2	3	0	0
Target Mode	**161.54**	**3**	**141.29**	**12.53**	0	**4**	**19**	**6**	0	0	**163.88**	**1.45**	0	**3**	**31**	4	**1**	0
		4	159.08	N/A	6	0	3	0	10	0	192.46	N/A	0	0	0	0	0	0
		5	188.70	N/A	0	0	1	0	0	0	215.49	N/A	4	0	1	0	7	1
		6	194.43	N/A	0	0	4	0	0	1	228.51	N/A	7	3	0	3	12	5
		7	207.10	N/A	1	0	6	0	3	1	236.26	N/A	0	0	0	0	0	6
		8	217.28	N/A	0	0	6	0	0	0	301.31	N/A	0	0	1	0	0	0
		9	230.14	N/A	4	3	0	3	8	10	330.92	N/A	1	0	4	1	0	0
		10	283.84	N/A	0	0	0	0	0	0	336.35	N/A	0	0	0	0	0	0

Key: MEF Between 5% and 20%; MEF Greater than 20%

TABLE 8.—COMPONENT WEIGHTS TEST ARTICLE VERSUS BASELINE FEM VERSUS CORRELATED FEM

Component	Test Article (lbs)	Baseline FEM (lbs)	%diff vs. test	Correlated FEM (lbs)	%diff vs. test
Fixture Base Plate	82.5	82.7	0.2	82.7	0.2
APS Base	38	36.2	4.7	36.2	4.7
APS Arm Frame Assembly	27.5	34.2	24.4	28.8	4.7
APS Total	65.5	70.4	7.5	65	0.8
Test Configuration Total	148	153.1	3.4	147.7	0.2

Once again, several parameters were considered in order to increase FEM modal frequencies: the thickness of the parts, the material properties used, the mass, and the boundary condition connecting the two antennas to the rest of the hardware. A micrometer was used to verify the thickness properties of the MGA and HGA. The material properties of MGA and HGA were also verified. The weights of the MGA and HGA matched their corresponding FEM weights. Table 8 summarizes the component weights of the hardware as compared to the fully assembly FEM. Table 8 shows that the overall weight difference between the hardware and FEM is less than 1 percent. Animations of the mode shapes for test mode 1 and the corresponding FEM mode showed exaggerated FEM antenna displacement. Because of this, additional RBE2 elements were added to the FEM at the connection between the antennas and the APS arm assembly. The updated model appears to correlate very well with the test data; the frequency of the target mode and the two secondary modes match the test results with less than 2 percent error, shown in Table 7.

Table 9 is a cross-orthogonality comparison of the first three test modes to the first three modes from the correlated FEM. The frequency model correlation goal was a frequency difference of less than ±5 percent between test data and the correlated model for the target and two secondary modes; which was accomplished. The primary mode shape model correlation goal was for the magnitude of the diagonal values be greater than 0.9 for the target and two secondary modes; which was accomplished. The secondary mode shape correlation goal was for the magnitude of the off-diagonal terms be less than 0.1 for the target and two secondary modes. This secondary correlation goal was accomplished for the target mode. Figures 13 to 15 compare the test and correlation FEM mode shapes for the first three modes and shows good agreement between them. The test mode shapes have been back-expanded to aid with visualization. Since all correlation goals have been met, the full APS dynamic simulator FEM is considered to be correlated.

TABLE 9.—CROSS ORTHOGONALITY TEST MODES VERSUS ANALYSIS MODES

			Analysis Modes				
			1	2	3		
		Freq (Hz)	116.95	121.55	163.88	%Freq Diff	Mode Shape Description
Test Modes	1	114.83	0.99	0.13	0.03	1.85	APS HGA Local X-Direction Bending Mode
	2	121.58	0.09	0.99	0.05	0.03	APS HGA Local Y-Direction Bending Mode
	3	161.54	0.04	0.07	0.99	1.45	Global Z Plate Bending HGA/APS out of phase

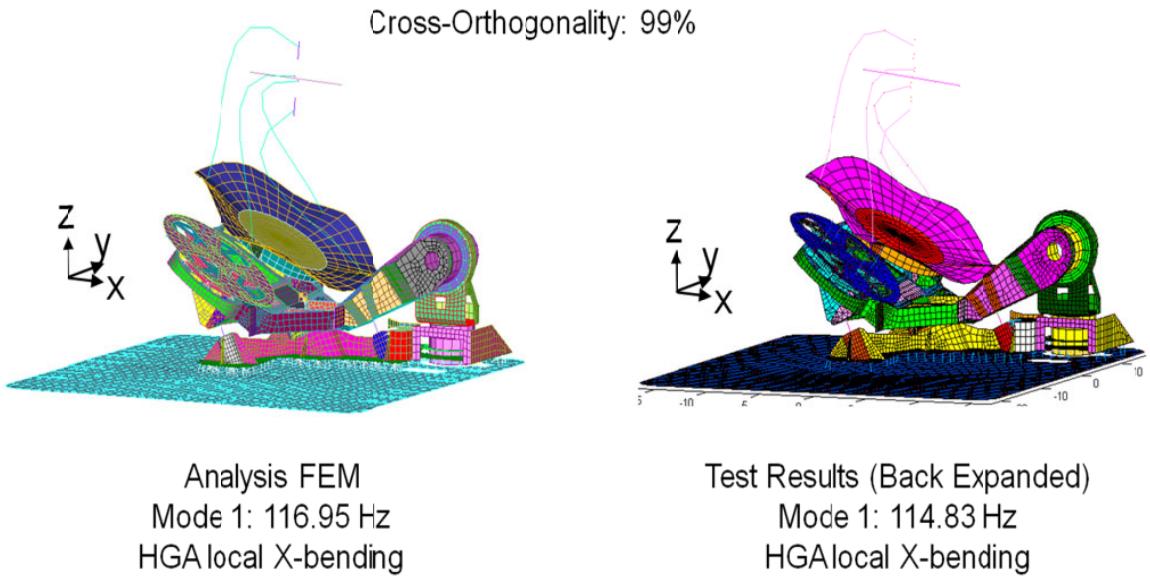


Figure 13.—APS HGA local X-direction bending mode shape.

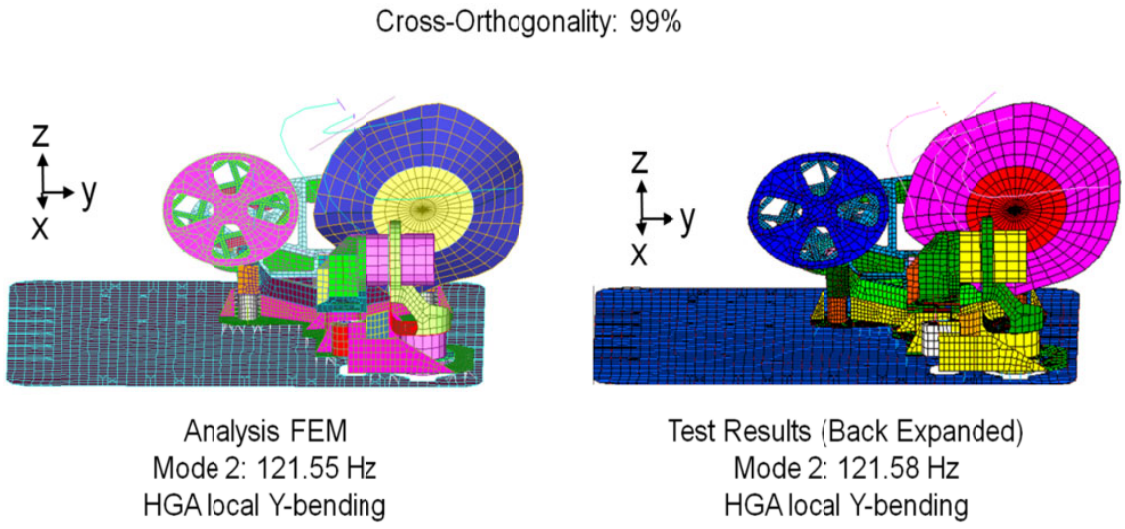


Figure 14.—APS HGA local Y-direction bending mode shape.

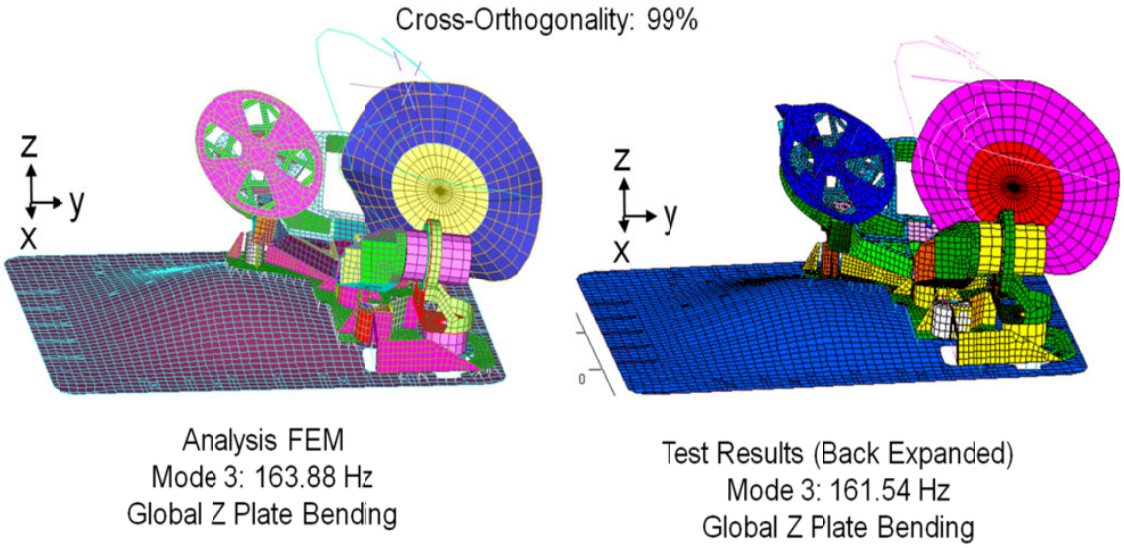


Figure 15.—Global Z plate bending HGA/APS out of phase mode shape.

8.0 Conclusions

The APS dynamic simulator FEM was successfully correlated based on the ISS model correlation criteria. Three modes were selected as target modes, one primary and two secondary. All selected modes had a frequency difference of less than 5 percent comparing test to analysis. The final cross-orthogonally table (Table 9) contained diagonal values greater than 0.9 and off diagonal values less than 0.1 for the primary target mode.

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-10-2012	Technical Memorandum	

4. TITLE AND SUBTITLE
CoNNeCT Antenna Positioning System Dynamic Simulator Modal Model Correlation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jones, Trevor, M.; McNelis, Mark, E.; Staab, Lucas, D.; Akers, James, C.; Suarez, Vicente, J.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
WBS 553323.05.01.06

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-18510

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITOR'S ACRONYM(S)
NASA

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM-2012-217747

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category: 39
Available electronically at http://www.sti.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 443-757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The National Aeronautics and Space Administration (NASA) developed an on-orbit, adaptable, Software Defined Radios (SDR)/Space Telecommunications Radio System (STRS)-based testbed facility to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities on the International Space Station (ISS). The Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) Project will provide NASA, industry, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in both the laboratory and space environment based on reconfigurable, software-defined radio platforms and the STRS Architecture. The CoNNeCT Payload Operations Nomenclature is "SCAN Testbed," and this nomenclature will be used in all ISS integration, safety, verification, and operations documentation. The SCAN Testbed (payload) is a Flight Releasable Attachment Mechanism (FRAM) based payload that will launch aboard the Japanese H-II Transfer Vehicle (HTV) Multipurpose Exposed Pallet (EP-MP) to the International Space Station (ISS), and will be transferred to the Express Logistics Carrier 3 (ELC3) via Extravehicular Robotics (EVR). The SCAN Testbed will operate on-orbit for a minimum of two years.

15. SUBJECT TERMS
Structural dynamics; Structural dynamic response

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email:help@sti.nasa.gov)
U	U	U	UU	24	19b. TELEPHONE NUMBER *(include area code)* 443-757-5802